Original communication

Estimation of sex from mastoid triangle − A craniometric analysis

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ABSTRACT

Estimation of sex is an important step in the evaluation of unknown human remains. Human skulls are shown to exhibit sexual dimorphism. The objective of the present study was to assess the mastoid region in sexing of unknown skulls. The present study was conducted on 118 (69 males and 49 females) dry skulls in a Medical College at India. The dimensions, area, perimeter, and the angles of the mastoid triangle were analysed for their utility in sex estimation. Non-parametric Mann−Whitney U test was employed to study the sex differences in the different variables. Receiver Operating Characteristic (ROC) curve was used for testing the overall ability of the variables in sex estimation. The present investigation confirms the low accuracy of the mastoid region in sex estimation. The study concludes that the mastoid triangle is a poor indicator of sex, and of limited significance without population reference.

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1. Introduction

Identification of the dismembered and skeletal remains is a vital part of any medico-legal investigation. The need to identify these remains arises in cases of mass disasters[1,2] and at times when the dead body is intentionally dismembered and mutilated into multiple pieces to conceal the identity of the victim. In such cases, the primary focus of investigation is on establishing the biological profile of the deceased by estimating age, sex, stature and ancestry.[3,4] Estimation of sex is one of the important parameters in establishing the biological profile of the unknown remains. Estimation of sex is based upon the sexual dimorphism exhibited by the human body.[5] The researchers have been conducting studies on estimation of sex from various human bones worldwide. These studies have focused on the long bones,[6–8] skull,[9–11] pelvis,[12–14] scapula,[15] clavicle,[16] sternum,[17–21] and hand and foot bones.[22–24]

Human skulls are shown to exhibit sexual dimorphism. According to Krogman and Iscan,[25] pelvis and skull provide the most accurate results in estimation of sex of unknown remains. At times,

extensive antemortem injuries, high intensity explosions, and post mortem mutilation by animals may result in fragmentation of human remains. Hence, there is a need to develop techniques to establish sex of the fragmentary remains. Studies on estimation of sex have been conducted on isolated regions of the cranium such as teeth,[26,27] nasal bones,[28] frontal bone,[29] occipital bone[30,31] foramen magnum,[9,32,33] and palate.[34,35] The mastoid region involving the mastoid process is highly resistant to physical damage and usually remains intact even in the very old and damaged skulls due to its protected anatomical position and compact structure.[36,37] Recent researches have shown that the mastoid triangle connecting the osteological landmarks; Porion, Asterion and Mastoidale can fairly determine the sex of an unidentified skull. This technique of sex estimation using mastoid triangle was introduced by Paiva and Segre[36] in a population of Sao Paulo, Brazil. Their study on the mastoid triangle was followed by other researchers[37–42] who have tested this technique of sex estimation in different populations with varying results.

The objective of the present research was to analyse the utility of mastoid triangle in estimation of sex in human skulls. Besides the various dimensions of the mastoid triangle, the area and perimeter, and the angles of the mastoid triangle are computed to study the sex-differences in these variables.

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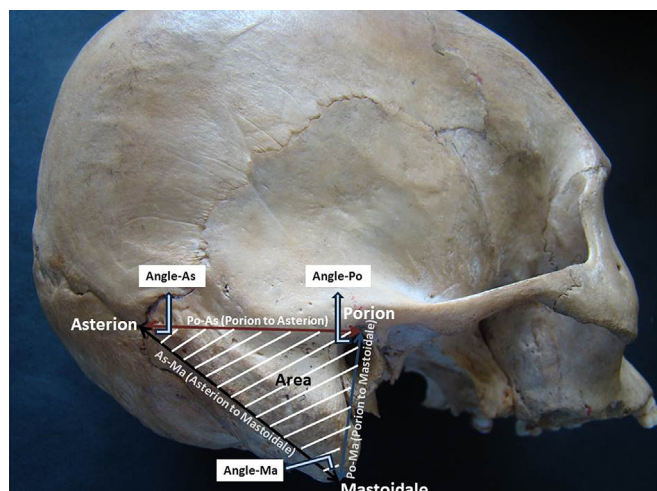
Fig. 1. Landmarks of the mastoid triangle.

2. Material and methods

2.1. Sample

The study was conducted on 118 dry skulls (69 males and 49 females) at Kasturba Medical College, Mangalore in India. The study sample included both anatomical specimens and skulls that were preserved in forensic cases after medicolegal investigations. The sex of the skulls was assigned by one of the authors (TK) based on morphological examination of the sexually dimorphic traits described in literature.[25] The size and shape of the mastoid was not considered during the process of assignment of sex since the present investigation involved the metric analysis of the mastoid region. The adult status of the crania was confirmed from the dentition and closure of sphenooccipital synchondrosis. All the damaged/deformed skulls and those that did not exhibit distinct sexually dimorphic features morphologically were excluded from the study.

2.2. Methods

An approval was obtained from the Institutional Ethical Committee of Kasturba Medical College, Mangalore before conducting this study. The mastoid triangle as originally defined by Paiva and Segre[36] was taken as the basis for this study. Following landmarks for mastoid triangle were marked on the right side of each cranium.

Porion (Po): Highest point on the surface of the external auditory meatus.
Mastoidale (Ma): Lowest craniometric point at the mastoid process.
Asterion (As): Meeting point of lambdoid, occipitomastoid, and parietomastoid sutures. Straight lines joining these three points (Po, Ma, and As) formed the mastoid triangle.

The following measurements were taken with the help of sliding callipers:

Po–As (Porion to Asterion): The straight distance between Porion and Asterion.
As–Ma (Asterion to Mastoidale): The straight distance between Asterion and Mastoidale.
Po–Ma (Porion to Mastoidale): The straight distance between Porion and Mastoidale.

Perimeter and area of the mastoid triangle were calculated. Perimeter of the mastoid triangle was taken as the sum of the three sides of the mastoid triangle (Po–As + As–Ma + Po–Ma), while Heron's formula was used for the calculation of area of the mastoid triangle in mm^2 following Kemkes and Gobel.[38]

The three angles of the mastoid triangle were calculated based on the three sides of the triangle using online software 'Solve triangle − SSS'[43] to find if the mastoid triangle varies in size as well as shape among males and females.

Angle–As: The angle between Po–As and As–Ma.
Angle–Po: The angle between Po–As and Po–Ma.
Angle–Ma: The angle between Po–Ma and As–Ma.

The landmarks and measurements included in the study are shown in Fig. 1. It needs to be highlighted here that the mastoid triangle does not constitute of a flat surface but a slightly curved one and hence, the area and angles calculated in the study cannot be considered as a true area/angle but area and angles for a two-dimensional planar view.

2.3. Analysis

The data were analysed using SPSS (Statistical Package for Social Sciences) version 11.5 software (SPSS, Inc., Chicago, IL, USA). Non-parametric Mann−Whitney U test was employed to find the sex differences in the different variables. Receiver Operating Characteristic (ROC) curve was used for testing the overall ability of the variables in sex estimation. Area under the ROC curve (AUC) denotes the discriminating power of variables in sex estimation. The higher the AUC, better is the sex discriminating potential of the variable. Level of significance was set at P-value <0.05.

3. Results

Descriptive Statistics for the dimensions of the mastoid triangle are shown in Table 1. Dimensions of the mastoid triangle were larger in males than females. The male−female differences were statistically significant for the distance between Porion and Asterion, ($P = 0.003$) and Porion and Mastoidale ($P = 0.007$). For the distance between Asterion and Mastoidale, the male−female differences were not statistically significant ($P = 0.097$). Perimeter and area of the mastoid triangle as estimated from the mastoid triangle

Table 1
Descriptive statistics: dimensions of the mastoid triangle, perimeter and area of the mastoid triangle.

	Males (*n* = 69)			Females (*n* = 49)			Z value	P value
	Mean	S.D	Range	Mean	S.D	Range		
Po-As	43.97	3.245	35−50	42.31	3.743	36−52	2.951	0.003
Po-Ma	27.43	3.056	22−35	25.73	2.548	21−30	2.692	0.007
As-Ma	48.68	4.667	37−59	47.16	4.749	39−58	1.658	0.097
Perimeter	120.09	8.237	97−134	115.20	10.120	97−136	2.609	0.009
Area	592.246	79.79	404−725	542.143	91.40	376−694	3.138	0.002

Po-As: Porion to Asterion; Po-Ma: Porion to Mastoidale; As-Ma: Asterion to Mastoidale.

dimensions are observed to be larger in males than females. Both perimeter and area of the mastoid triangle show statistically significant male–female differences (Table 1). None of the angles of the mastoid triangle were shown to elicit statistically significant sex differences (Table 2). A considerable degree of overlapping is observed for the mastoid triangle dimensions. Frequency distribution of mastoid triangle dimensions is shown in Table 3. Similar observations are made with regard to the perimeter and area of the mastoid triangle (Figs. 2 and 3).

ROC analysis indicates that the sexing potential was maximum for the area of the mastoid triangle (67.0%) followed by distance between Asterion and Porion (65.8%), distance between Porion and Mastoidale (64.5%), and Perimeter of the mastoid triangle (64.1%). Observations of the ROC analysis applied to find the predictability of each variable in sex estimation are shown in Fig. 4.

4. Discussion

The skull plays a vital role in distinguishing the sex of the fossil and archaeological remains. There are two basic methods of sexing the human skull; morphological and morphometric. The morphological method is based upon the observation of certain sexually dimorphic traits of the skull. The morphometric method of sex estimation however, depends upon taking certain measurements on the skull. This method utilizes the traits of robustness that enable differentiation between males and females. Metric analysis has merits over the morphological analysis as the former is more objective and provides greater statistical weight than the latter.[38,40,44]

Mastoid region has drawn the interest of researchers for its utility in sex estimation since long. The size of mastoid is of significance in discriminating sex using both morphological and morphometric analysis. The size of the mastoid is one of the Krogman's traits used frequently by forensic experts in distinguishing male and female skulls based on morphological examination.[45] In a study on credibility of morphological sex estimation on 19th century samples, Rogers[45] assigned a combined rank of 3 for the size of the mastoid. Later, Williams and Rogers,[46] in a similar study assigned a combined rank of 1 for the size of mastoid in sex estimation in modern sample. Hence, mastoid was considered as a high quality trait in sex estimation.

Due to a marked sexual dimorphism in the mastoid region of the cranium, many researchers have investigated this region using metric methods. Nagaoka et al.,[39] Sumati et al.[47] and Gupta et al.[42] utilized several measurements of the mastoid process and studied its accuracy in sex differentiation. Nagaoka et al.[39] measured the height, width and length of the mastoid process in medieval to early modern Japanese skulls and concluded that the accuracy of sex classification was more that 80% when single parameter was used, and accuracy of 82–92% was achieved when mastoid height and width were taken together for sex estimation. Sumati et al.[47] analysed the length, breadth and antero-posterior diameter of the mastoid process and calculated the size of mastoid process in a modern North Indian sample. They found that the mastoid process correctly classified sex in 76.7% crania included in the study. Gupta

et al.[42] observed an accuracy of 90% for the mastoid process in sexing the crania and stressed that the mastoid length was the best in determining the sex of the South Indian crania. Franklin et al.[48] however, has reported a low sexing accuracy of 68% for mastoid length in sexing of indigenous South African crania. A detailed study on sex estimation from mastoid process using metric analysis on a modern North Indian autopsy sample was published by Saini et al.[37] Saini et al.[37] utilized eight different measurements on mastoid process. The prediction accuracies using each variable in direct discriminant analysis in their study[37] ranged between 68.1% and 75.4%, while in step-wise analysis, asterion-mastoidale and mastoid breadth provided an accuracy of 87%. Different studies have thus, used different landmarks and measurements that besides population differences may be responsible for the variations in the levels of accuracy reported in these studies.

In the present research, all the dimensions, area, and perimeter of the mastoid triangle were found to be larger in males than females. This may be attributable to the generally larger size of the male cranium as compared to the female cranium. The sex differences in the size of mastoid process can be attributed to the variable duration of growth in males and females.[37] The mastoid region of the cranium is one of the later growing regions and such regions show higher degree of sexual dimorphism in the adulthood.[37,45] In the present investigation statistically significant sex differences were observed for the distance between Porion and Asterion, and between Porion and Mastoidale. The distance between Porion and asterion, considered as mastoid length in the Japanese skulls showed statistically significant male–female differences similar to that reported in a study on Japanese skulls.[39] The mastoid length in Japanese skulls was comparatively larger among males (49.0 ± 3.47 mm) and females (47.0 ± 2.7 mm) than those observed in our study, thus, suggestive of population differences in the measurements of the mastoid. Previous studies on the dimensions of mastoid triangle[37,38,41] have observed statistically significant sex differences for all the three arms of the mastoid triangle. In the present study, statistically significant sex differences were not observed for the distance between Asterion and Mastoidale, which is similar to the observations of Kemkes and Gobel[38] who found this dimension to be statistically insignificant in estimation of sex in the German sample. A study on Brazillian skulls[40] observed

Table 3
Frequency distribution of the mastoid triangle dimensions in males and females.

Range	Male (n = 69)			Female (n = 49)		
	As-Ma (%)	Po-As (%)	Po-Ma (%)	As-Ma (%)	Po-As (%)	Po-Ma (%)
20–24	–	–	08 (11.6)	–	–	14 (28.6)
25–29	–	–	42 (60.9)	–	–	34 (69.4)
30–34	–	–	18 (26.0)	–	–	01 (02.0)
35–39	02 (02.8)	03 (04.3)	01 (01.4)	01 (2)	06 (12.2)	–
40–44	10 (14.4)	33 (47.8)	–	11 (22.4)	34 (69.3)	–
45–49	29 (41.9)	28 (40.5)	–	16 (32.6)	07 (14.2)	–
50–54	25 (36.2)	05 (07.2)	–	19 (38.7)	02 (04.0)	–
55–59	03 (04.3)	–	–	02 (4)	–	–

Po-As: Porion to Asterion; Po-Ma: Porion to Mastoidale; As-Ma: Asterion to Mastoidale.

Table 2
Descriptive statistics: angles of the mastoid triangle.

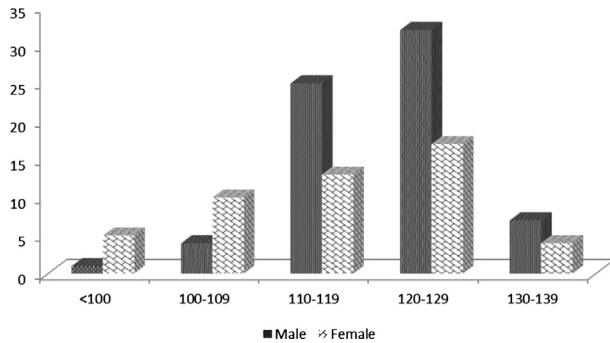| Angles	Male (n = 69)			Female (n = 49)			Z value	P value
	Mean	S.D	Range	Mean	S.D	Range		
Po-Angle	82.62	8.23	66.51–98.18	83.97	5.60	71.79–90.54	0.415	0.678
Ma-Angle	63.43	6.09	51.04–71.96	63.21	4.07	56.43–71.79	0.060	0.952
As-Angle	33.92	4.65	24.79–44.87	32.838	2.82	26.63–41.51	1.356	0.175

Po: Porion; Ma: Mastoidale, As: Asterion.

Fig. 2. Frequency distribution of the mastoid triangle perimeter in males and females.
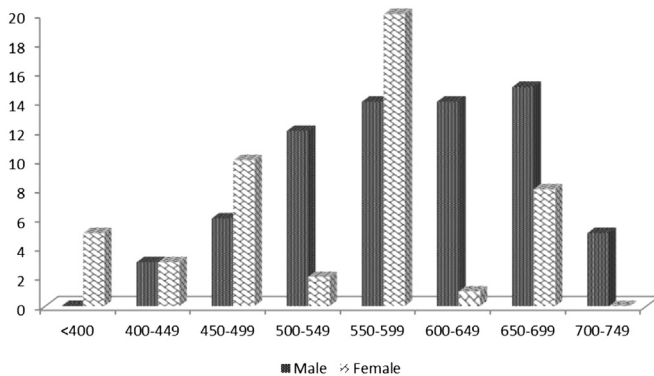

Fig. 3. Frequency distribution of the mastoid triangle area in males and females.

statistically significant sex differences only for the distance between Porion and Mastoidale. A comparative account of the dimensions of the mastoid triangle in the previous studies is shown in Table 4. Distance between Asterion and Mastoidale was observed to be the longest arm of the mastoid triangle in our study as well as all the previous studies[38,40,41] except for the study by Saini et al.[37] where the distance between Porion and Asterion was observed as the longest arm of the mastoid triangle. It is evident from the ROC analysis in the present study that the sexing potential of mastoid triangle dimensions is low. Overall accuracy of measurements using ROC analysis in a study from North India[37] was higher than ours and the most effective single measurement was found to be the distance between Asterion and Mastoidale that showed an accuracy level of 75.4%. In our study, however, distance between Asterion and Mastoidale did not show statistically significant sex

differences. A study from Thailand[41] has shown higher accuracy levels on utilizing discriminant function analysis than those reported in the present study. Our observations that are suggestive of a lower accuracy level of mastoid triangle dimensions are similar to those reported by Kemkes and Goble.[38]

To the best of our knowledge and literature search, since the introduction of mastoid triangle by Paiva and Segre,[38] four studies have been published on mastoid triangle and its ability in estimation of sex.[38,40,41,49] Paiva and Segre[36] in a xerographic study of dry skulls in a population of Sao Paulo, Brazil calculated the area of right and left mastoid triangle and then added the two areas to calculate the total area. They observed a statistically significant difference in right, left and total area of the triangle and recognized 60%, 51.67%, and 36.67% overlapping of male and female values for right, left, and total area of triangle respectively. Paiva and Segre[36] concluded that the total area ≥ 1447.40 mm^2, and ≤ 1260.36 mm^2 was indicative of male and female cranium respectively. Though the authors state that xerographic study is easy to execute and have detailed the technique of obtaining a xerographic copy of each side of mastoid region, its validity with regard to reproducibility and repeatability needs to be tested. Moreover, for the well-defined landmarks of mastoid triangle, direct measurements should be preferred over the indirect ones such as the xerographic copies. Probably for the same reason, all the latter studies in different populations were based on direct measurements of the skull.[38,40,41,49] The results of the present study indicate that statistically significant sex differences exist in both area and perimeter of mastoid triangle connecting the landmarks porion, asterion and mastoidale and are thus, in agreement with the observations of the previous researchers.[38,40,41,49] Galdames et al.[40] however, has reported significant sex differences in the mastoid triangle area on the right side only. Comparisons of the area of mastoid triangle as reported in the previous studies are shown in Table 4. Maximum dimensions and area of mastoid triangle are observed in Thai population,[41] while minimum dimensions and area are observed in an autopsy study from Northern part of India.[49] Mastoid triangle area in Indian studies is significantly lesser than that observed in the studies from Brazil,[40] Europe,[38] and Thailand.[41] In fact, the mean mastoid triangle area among males in studies from India is far less than the mean mastoid triangle area in females in the studies from Brazil,[40] Europe,[38] and Thailand.[41] When compared to the mastoid triangle area observed in the other study from India,[49] the mastoid triangle area was observed to be larger in the present investigation. Observations of the present study are thus, in agreement with Kemkes and Gobel[38] that area of mastoid triangle is of limited significance without population reference. The accuracy of the area of mastoid triangle in sex estimation in the present
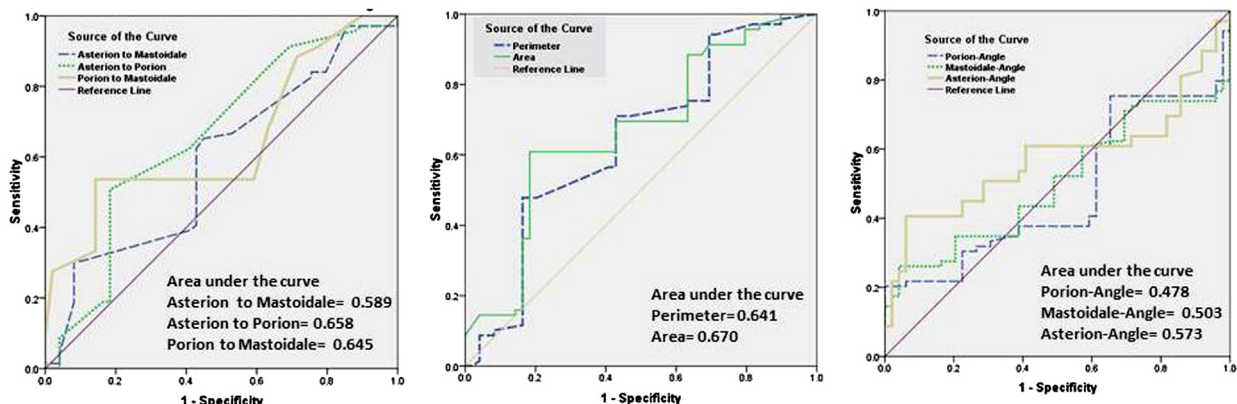

Fig. 4. ROC curve for the dimensions, perimeter, area, and angles of the mastoid triangle.

Table 4
Comparative analysis of observations of previous researchers on mastoid triangle dimensions (mm) and area (mm^2) on the right side.

Study	Population/study region	Po-Ma		As-Ma		Po-As		Area	
		Male	Female	Male	Female	Male	Female	Male	Female
Paiva and Segre[36]	Brazil	–	–	–	–	–	–	752.1	608.7
Kemkes and Globel[38]	German	30.9	28.9	50.5	49.4	48.6	46.3	717.6	655.9
	Portugese	31.5	28.4	49.5	45.4	47.7	45.1	718.9	609.5
Galdames et al.[40]	Brazil	30.7	27.6	50.2	48.3	47.5	46.7	703.3	624.1
Manoonpol and Plakornkul[41]	Thailand	35.1	31.2	57.2	52.2	53.5	49.6	912.7	752.5
Singh et al.[51]	North India	23.1	21.7	45.2	41.1	41.9	39.0	478.0	412.1
Present study	South India	27.4	25.7	48.7	47.2	43.9	42.3	592.2	542.1

Po-As: Porion to Asterion; Po-Ma: Porion to Mastoidale; As-Ma: Asterion to Mastoidale.

study has been found to be low and similar to that reported by previous researchers.[38,40,41,49] Kemkes and Gobel[38] observed that using discriminant function analysis, only 65% of all skulls could be correctly identified. Singh et al.[49] observed sexing accuracy of the mastoid area as 61%. Singh et al.[49] also observed that the accuracy of the area of mastoid triangle varies in different age groups, an observation not explored in any of the previous studies. The accuracy levels were comparatively higher in the Thai population. The location of asterion and its anatomic relationship with other cranial structures is thought to be a confounder that may be the cause for reduced sex differences in the region.[38] The fact that the position of the asterion varies with progression of age in a population specific manner is highlighted in previous anatomical and clinical studies.[37]

The variations in the observations of previous studies on different populations confirm the existence of population specific differences exhibited in the skull. These can be attributed to the environmental and nutritional influences and to the variability in the position of landmarks of the skull in different populations.[37] Kemkes and Gobel[38] evaluated the validity of the technique of Paiva and Segre,[36] and concluded that although the area of mastoid triangle shows statistically significant sex differences, the technique is of limited practical utility in assessing individual skulls without population reference. In the study by Kemkes and Gobel,[38] the Portugese cemetery sample showed greater sexual dimorphism than the German sample with regard to mastoid triangle. Observations on the mastoid triangle area in the two studies from Brazil differ from each other. These variations however, can be attributed to the differences in the methodologies adapted in the studies.[36,40] Similarly on comparing the mastoid triangle dimensions in the two previous studies from Northern part of India,[37,49] variations are obvious despite the fact that both the studies are conducted on autopsy samples in a modern population. These variations can probably be attributed to the fact that India is a country where significant ethnic and population diversity exists.[50] Delhi being the capital and metropolitan city in Northern part of India has a mixed sort of population from all over India. The study by Singh et al.[49] though was based on autopsy examinations at an Institute in Delhi, thus, cannot be considered as representative of any specific population group. However, the study sample in the study by Saini et al.[37] can be considered as more representative of population from the Northern part of India. It is a well-established fact that the standards developed on skulls of one population should not be used on the other population groups owing to population variations. With intermixing of populations in the modern world it may not be practically possible to assign a population reference to a skull brought for examination, thus, further reducing the applicability of mastoid triangle in sex estimation of unknown skulls.

The angles of the mastoid triangle did not exhibit any sexual dimorphism. Our observations on the angles and perimeter of the mastoid triangle cannot be compared per se since no previous studies are available on these variables. However, insignificant sex

differences in the mastoid angles are suggestive that the mastoid triangle is proportionately smaller in females than males. Angular and ratio measurements are used to depict the 'pattern' and minimize the effects of size increases or changes.[51] Our observations thus, further confirm the views that estimation of sex of adult skulls depend on the larger size and robustness of the male skulls than females.[39] It is shown that the females have a smaller cranium than males, both absolutely and relatively which is attributed to the differences in the dimensions and rate of growth of the skull. Boys experience a cranial growth spurt even before puberty, which is not seen in girls.[52] Besides, a relatively greater development of mastoid process in males may be a response to the stronger muscle actions.[37,45] The muscles in the mastoid region are attached over a relatively larger area in males than females. The morphological features whose development is related to insertion and action of major muscle groups are reported to be better indicators of sex.[37,53] The present investigation confirms the low accuracy of mastoid dimensions and mastoid area in sex estimation. The results of the present investigation are however, indicative of the consistency between the sexing based on the measurements of the region and the morphological examination of the sexually dimorphic traits that were used to assign the sex to the skulls. Measurements used in the studies on mastoid triangle are straight distances between the landmark points and sex differences may vary for the actual distance along the curved surface between the landmark points. It can be concluded from the study observations and based on the comparative analysis of the previous studies that the mastoid triangle is a poor indicator of sex, and of limited significance without population reference.

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